ENERGETICS

Ideas and information for using energy in agriculture effectively.

Energy Ontario

Ontario

Published by the Ontario Ministry of Agriculture and Food · Agricultural Energy Centre · 801 Bay Street · Toronto · M7A 2B2 · (416) 965-9519

Agdex 440
717.3

RETROFIT OF A HOG FINISHING BARN TO NATURAL VENTILATION

Partial funding provided by the Ontario Ministry of Energy

Managed by the Agricultural Energy Centre

Doug Trivers
OMAF Energy Centre
School of Engineering
University of Guelph
GUELPH, Ontario. N1G 2W1

Co-operator
Rudy van Dieren
R.R. #7
ST.MARYS, Ontario. N0M 2V0

November 1986

ABSTRACT:

A mechanical ventilation system in a hog finishing barn was converted to cathedral ceiling type natural ventilation. The 18 m width is greater than that of typical naturally ventilated barns. The barn was monitored to determine if the system can provide adequate air mixing and distribution. Results indicate the system provides good winter humidity control and summer temperature control. The health and performance of the feeder hogs has improved.

RETROFIT OF A SWINE BARN TO NATURAL VENTILATION

Introduction.

Natural ventilation has become popular in renovated and newly constructed swine barns. The savings in energy are self evident. The most common types of natural ventilation are the cathedral ceiling style barns with a continuous ridge outlet and the modified open front or MOF type barn. There are several such barns operating successfully throughout Ontario.

The advantages natural ventilation has over fan ventilation, as listed by Bird [1], are as follows:

1. Reduced operating costs. The cost of operating a fan ventilation system for a well insulated barn that has the capacity of finishing 1000 market pigs per year has been measured at about $0.75 to $1.00 per pig marketed. This cost is virtually eliminated. Equipment maintenance costs are likely to be less.

2. The level of noise within the building is greatly reduced. This reduces stress on the livestock and the operator. Unusual animal sounds are more easily heard. Conversations between workers are easier.

3. Odour, dust and humidity control are all improved. There are differences from barn to barn, but in general, naturally ventilated buildings are providing better air quality.

4. Air speeds are low. There is less mixing of incoming air with air already in the building. Natural ventilation tends to replace the stale air with fresh, whereas fan ventilated buildings tend to mix and dilute the stale air with fresh air.

5. A power failure will not stop natural ventilation. Pneumatic door have a reserve of compressed air to continue to operate the doors. Electrically powered doors can be powered by a small capacity standby generator system. Manual operation is also possible.

Background

In the spring of 1984 Mr. Rudy van Dieren, a Perth County pork producer approached the Ontario Ministry of Agriculture and Food (OMAF) for assistance in troubleshooting a ventilation problem in a hog finishing barn. An inspection was made by Agricultural Engineer Franklin Kains and Swine Specialist Richard Smelski.

The finishing barn dimensions are 18 000 mm by 24 000 mm with a 2700 mm high ceiling. There is capacity in the barn to finish about 425 hogs. The ceiling was insulated with 100 mm of fiberglass insulation. The walls were covered with a combination of 25 mm styrofoam and used 100 mm fiberglass bat insulation. Inspection showed that the vapour barrier was badly perforated. As a result the insulation had been entirely saturated several times. In addition, large amounts of the insulation had been removed or damaged by rodents. The insulation was in need of replacement.

Ventilation was provided by a bank of six fans located at one end of the barn. Inlet was provided by two shutter-type inlets at the other end of the barn. This ventilation did not provide an adequate environment for the feeder pigs. An attempt was made to correct the ventilation problem using air bags to alter the air distribution pattern. The air bags still did not provide a suitable environment.

Following the OMAF inspection, a recommendation was made to remove the false ceiling and convert the structure to a cathedral ceiling type naturally ventilated barn. However, the 18 m width is far wider than that of typical naturally ventilated barns. There was concern that the system may not provide adequate ventilation throughout the building.

Objectives

While natural ventilation has been shown to work well when incorporated into the design of new livestock buildings, little work has been completed in investigating the performance of older structures retrofitted to natural ventilation. The objectives of this project are outlined as follows:

1. To retrofit the barn to natural ventilation, and to monitor the resulting environment and animal performance.

2. To determine if a naturally ventilated barn of these dimensions can provide a suitable environment for hog finishing.

3. To develop guidelines from the results of the study to provide assistance to other operators interested in trying a similar retrofit.

Description of the Retrofit

Several structural changes were made to the barn in the summer of 1984. Figure 1 is a sketch of the barn layout after the retrofit to natural ventilation. A description of the modifications made to the barn is as follows:

1. The false ceiling, vapour barrier and all the old insulation which had been suspended from the roof trusses was removed.

2. The fans were removed and the openings were sealed up.

3. The entire barn was insulated with spray-on urethane foam insulation applied to the inside surfaces. Approximately 40 mm (RSI 1.4) were applied to the walls and 50 mm (RSI 1.7) applied to the ceiling.

4. A continuous ridge opening was installed in the peak of the roof. A short chimney-like structure was installed to assist in the creation of an upward exhaust draft. Details of the ridge opening are shown in Figure 1 and Figure 2.

5. A trough was installed inside the barn, below the ridge opening as shown in Figure 2. This serves as a door to close the ridge using a manually operated hand winch. This also catches snow and rain. A 50 mm plastic hose drains water from the trough to the outside.

6. Bottom pivoting wall vents were installed along both sides of the barn as shown in Figure 1. The wall vents were constructed by the operator. A frame was fabricated with aluminum channel at a local welding shop. Galvanized steel was riveted to the outside of the door panel. The space inside was filled with fiberglass bat insulation. A vapour barrier was placed over the insulation and plywood was riveted to the inside of the panel to hold the insulation and vapour barrier in place. Figure 3 shows a sketch of a ventilation wall vent.

7. All openings were covered with wire mesh to prevent birds from entering the barn.

Operation of the Ventilation System

The operation of the natural ventilation system is controlled by a Powervent™* thermostat control unit and manual adjustments made by the operator. The thermostat control is located in the centre of the barn. The thermostat operates a motorized winch system which opens the wall vents along both sides of the barn. A manually operated switch on the thermostat allows the operator to set the maximum opening limit.

Mr. van Dieren felt that the control system was opening the wall vents too much during the winter months. As a result the room temperature was dropping too low. To prevent this, the wall vents on the west side of the barn were disconnected from the control unit. Since Mr. van Dieren is in the barn at least four times a day he felt he could adjust the west wall vents manually.

The ridge opening is also controlled manually using a hand-winch and cable system. An automatic control unit was not used to reduce the cost of the retrofit. The operator wanted to evaluate the performance of the system before proceeding with the additional expense.

---

* Note: The use of specific manufacturers names is for description only and does not imply an endorsement of that equipment or discrimination of similar equipment by the author or the Ontario Ministry of Agriculture and Food.

For winter operation, when the outside temperatures are very cold, the side vents are kept closed. It is difficult to obtain a good seal around the doors. Air that leaks around the doors provides some of the fresh air requirement. Additional fresh air enters through the ridge opening. Cold, fresh air enters at the ridge and drops into the barn. As the air enters it mixes with the barn air and gradually warms up. At the same time warm air masses move towards the ridge and escape. Temperature control is obtained by controlling the rate of air exchange with manual adjustments of the ridge opening.

On warmer days, when the outside temperature is above 5°C, the side vents are opened to allow larger volumes of fresh air into the barn. When the system is operated this way, the air flow pattern is different. In this case fresh air enters through the side vents, mixes with the barn air, and is gradually warmed up. As the air heats up it moves upward and out of the ridge.

In the summer months, after the night time temperature no longer drops below about 5°C, the side vents are left open all night. The operator adjusts the west wall vents for the forecast weather conditions. The automatic control unit adjusts the east wall vents for temperature control. Different air patterns develop in the summer. As explained earlier, cooler fresh air enters the side vents, mixes with the barn air, and exits at the ridge vent. In addition to this, cross flow patterns develop as a result of wind action. The nature of the cross flow depends on the direction and velocity of the wind.

Monitoring

The temperature and relative humidity was monitored From October 29, 1984 until July 31, 1985 to determine if the natural ventilation system provides an adequate environment for growing feeder hogs.

The temperature was also measured at four points in the room using maximum-minimum thermometers. Readings were taken from these thermometers once each day. The locations of these thermometers are shown in Figures 1 and 2. A location description is as follows:

T_a - at pen level on the automatic side of the barn

T_m - at pen level on the manual side of the room

T_r - at the ridge opening near the South end of the barn

T_c - at pen level near the centre of the barn

Two recording thermohygrographs were placed in the barn to measure the weekly the temperature and humidity fluctuations. One unit was installed at about eye level near the centre of the barn. The second unit was located in a vacant pen, at one end of the barn, at pig level. The locations are shown in Figure 1 and 2 as TH_1 and TH_2.

Performance data included feed records and weights from sale receipts.

Results

The results are shown in several graphs located in Appendix 1. Figures 4 and 5 show typical temperature and humidity variations, as measured by the thermohygrographs, for winter and summer operation, respectively. As would be expected the results indicate the temperature is often from 2°C to 5°C cooler at the floor of the barn than at operator eye-level during both the summer and winter operation. The daily temperature fluctuation measured by the thermohygrographs is +/- 5°C. This fluctuation tends to be larger in the winter than in the summer.

As expected the humidity levels are higher on average, in the winter than in the summer. Figure 4 shows that the humidity levels recorded for December 17, 1984 range between about 75% and 87%. These results are typical for the winter operation, although on extremely cold days the humidity did at times rise above 90%. In the summer, the humidity fluctuation in the barn was much greater. The levels were in a range of between 40% and 95%. The outside humidity variation is much larger in the summer than for winter. With the large amount of air exchange in the summer, the barn humidity tends to follow the outside humidity. Figure 5 shows the typical humidity variation in the barn during summer operation.

Figures 6 and 7 display the daily maximum to minimum temperature range for the barn and outside, for two periods of the year. The outside temperature was not measured on site. These values were obtained from Stratford weather data. Figure 6 shows that for December and January 1985 the barn temperatures were in a range from 5°C to 22°C. For the majority of the time the minimum temperature is above 10°C. The outside temperature range for this period is much lower. These results indicate the winter heat balance of the barn is adequate most of the time. It may be possible to prevent these low temperatures with better control of the vents. At times the stocking density was only 70% of capacity. Maintaining a greater stocking density may also help to maintain a higher barn temperature.

Figure 7 shows the barn and outside temperature ranges for the months of June and July 1985. In this case the daily maximum barn temperature fluctuates over a range of 14°C to 28°C. Since during the summer the barn is kept nearly completely open the temperature in the barn follows the outside temperature more closely.

Figures 8 through 11 show other temperature gradients observed in the barn. Figures 8 and 9 compare the maximum daily temperature for three zones, the automatic side, centre and manual side. For both summer and winter operation the automatic side and the centre appear to be at about the same temperature. This is expected since the thermostat control is located in the centre of the room. The manual side is from 1°C to 2°C cooler in the summer and winter.

Figures 10 and 11 compare the daily maximum temperature at the ridge peak and the centre eye-level locations for summer and winter operation. The figure shows that for about half the time the ridge is 1°C warmer than the eye-level location. For the remainder of the time the opposite is true. A similar analysis was performed for the minimum daily temperatures in the barn and the results were the same. These results indicate that the temperatures are fairly uniform in the area above operator eye-level. This also indicates that small temperature gradients are sufficient to provide proper mixing action.

Cost Analysis

The cost of the modifications to the barn are outlined as follows:

Spray-on Urethane Insulation		$7370
Control System		$1074
Outside Labour		$ 565
Electrician		$ 417
Lumber		$ 477
Other misc.		$ 103
Side Vents		
frames -aluminum	$435	
frames - welding	$270	
insulation	$ 85	
galvanized steel	$128	
plywood	$175	
misc. hardware	$ 85	
		$1178
Ridge Trough		
flat steel	$ 45	
2 Winches	$ 64	
lumber	$477	
cable and clamps	$134	
misc. hardware	$ 36	
		$ 756
Total Cost of Retrofit		$11,940

To estimate a payback period for the retrofit to natural ventilation, the benefits of the modifications must be determined. One such benefit is the reduction in the cost of electricity required to operate the fans. The electrical energy consumption for the barn has been estimated using the procedure outlined in Appendix 2. From this analysis, the cost to power fans with electricity would be approximately $750 annually. Assuming the barn insulation should have been upgraded, the total cost of the retrofit would be $11,940 - $7370 = $4570. The simple payback, based on the fan operating cost reduction alone is as follows:

$$\text{Simple Payback} = \frac{\text{Retrofit Cost}}{\text{Annual Savings}} = \frac{\$4570}{\$750/\text{yr}} = 6 \text{ years}$$

This payback period is longer than what most operators consider acceptable. There are however, other benefits to consider. Since the installation of the natural ventilation system the operator has noticed a dramatic decrease in the number antibiotic injections given to the feeder pigs. Although records of this were not kept Mr. van Dieren estimates the number of injections has gone from 3-5 per week to only 2-4 each month. He has seen a significant reduction in herd health costs.

Prior to the installation of the natural ventilation system, pneumonia was a common cause of death in the herd. With the natural ventilation system the few deaths that have occurred have been by heart attack. Recently, the lungs of 10 finished hogs were analyzed for pneumonia damage. Only two of those tested showed more than minimum infection and the average for the group was 1.75%. The industry target is below 10% infected area.

Another benefit which is apparent is a reduction in the number of days to market and an improvement in feed conversion. The finished hogs are sent to the market at about 100 kg at an average age of 180 days. Feed records from contract feeding hogs for two years when the fan system was in operation showed feed conversions of 3.6 to 3.3 kg feed/ kg gain. Results from the Shur Gain "Pork Score" program indicate feed conversions of 2.65 and 2.75 for 1984 and 1985, respectively. Assuming 75 kg of gain are put on each finishing hog, the savings in feed amounts to:

$$\text{Feed Savings} = (3.45-2.70)\ \text{kg feed/ kg gain} \times 75\ \text{kg gain}$$
$$= 56\ \text{kg feed/hog}$$

Assuming a feed cost of $160/tonne (from November 1986 Pork News and Views) or $0.16/kg, the savings is about $9.00/hog finished. If the improvement in the environment is even partly responsible for the better feed conversion, this savings will significantly reduce the payback period.

Conclusions

The operator is very pleased with the performance of the natural ventilation system. During summer operation, the air quality is noticeably improved from that obtained by the previous fan system. In winter time the improvement is not quite as dramatic. Humidity buildup still occurs on very cold days. This can be reduced at the cost of permitting a lower inside temperature.

The operator is not very concerned with temperatures down to about 10°C. He feels that with the low air speeds he can keep the barn temperature lower, and still maintain a higher effective temperature than provided by the drafty fan system. Also, with the proper density of hogs in each pen, they are able to regulate their heat loss by huddling.

The results of this study indicate that the natural ventilation retrofit was successful for the barn, in spite of the 18 m width. The barn appears to provide a suitable environment for finishing hogs. Despite the wide range of daily temperature fluctuation there is evidence to suggest the performance of the finishing hogs has improved in terms of both health and feed conversion. In terms of providing an environment for optimum hog performance, the system could use some fine-tuning. The daily temperature fluctuation may be too extreme for optimum hog performance. An automatic control system for the entire system would likely help to reduce this variation.

The following list is a summary of some features of the ventilation system. These guidelines may prove useful to producers interested in completing a similar ventilation retrofit.

1. The OMAF Ventilation Manual recommends a minimum exhaust ratio of 1:100 exhaust area to floor area. For this structure the exhaust ratio is 2.8:100 or about three times the recommended limit. The ridge opening is 0.61 m wide.

2. Similarly, the minimum inlet ratio is specified as 1:25 inlet area to floor area. For this structure the inlet ratio is 1.3:25 or 30% greater than the minimum recommended level.

3. The ventilation manual states a high ceiling, greater than 3 m is desireable. For this barn the ceiling is 5.7 m. The volume of the building is 2450 m^3.

4. Winter operation of the ventilation system involves closing the side wall vents. Part of the fresh air requirement is provided by leakage around the side vents. Additional fresh enters through the ridge vent. The rate of air exchange is controlled by adjusting the ridge vent opening.

5. In warmer weather, additional fresh air is provided by opening the side vents. The ridge vent is manually controlled to control the amount of air exchange.

6. For summer operation the ridge vent and side vents are left fully open and wind action is relied on to ensure adequate air exchange.

The natural ventilation retrofit, when constructed and managed as described in this report, provides an environment suitable for finishing hogs.

REFERENCES

1. Bird, N.A. Controlled Environment with Natural Ventilation in Gable Roofed Barns. Agricultural Engineering Service, unnumbered OMAF publication.

2. Bird, N.A. A Swine Finishing Barn with Automatically Controlled Natural Ventilation. ASAE Paper 81-201.

3. Bird, N.A. Confinement Swine Housing. Agriculture Canada Publication 1451. 1979.

4. Curtis, S.E. Environmental Management in Animal Agriculture'. The Iowa State University Press, Ames, Iowa. 1983.

5. Huffman, H., et al. Ventilation Manual. Published by the Ontario Ministry of Agriculture and Food.

6. MacDonald, R.D., G. Houghton and F.A. Kains. Comparison of a Naturally Ventilated to Mechanically Ventilated Hog Finishing Barn. Paper No. 85-402, Presented at 1985 CSAE annual meeting.

7. Ontario Ministry of Agriculture and Food. Pork News and Views. Animal Industry Branch unnumbered periodical, November - December 1986 Issue.

APPENDIX 1: FIGURES

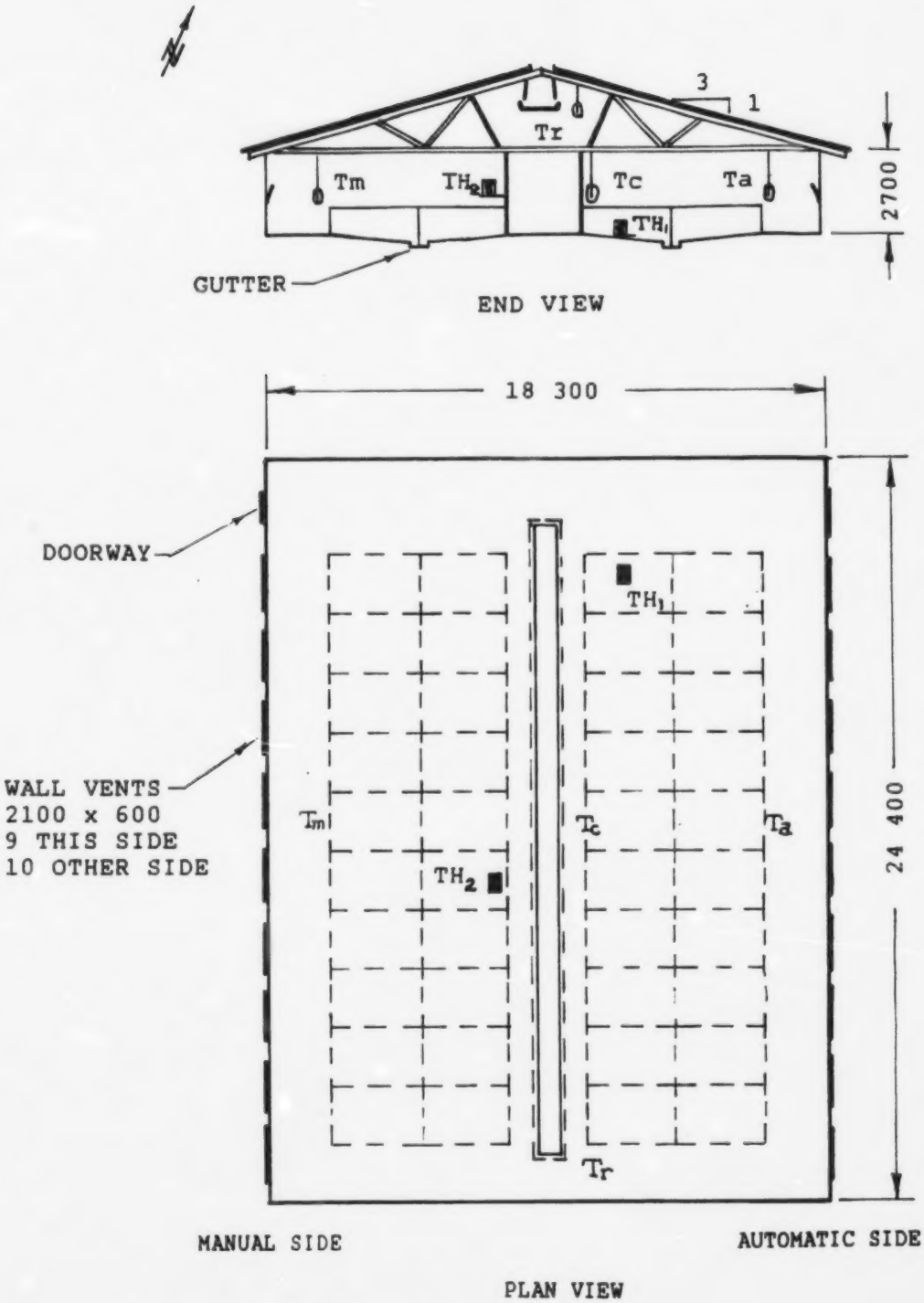

Figure 1: Sketch of the Finishing Barn Layout Showing Temperature Measurement Locations. (All Dimensions mm).

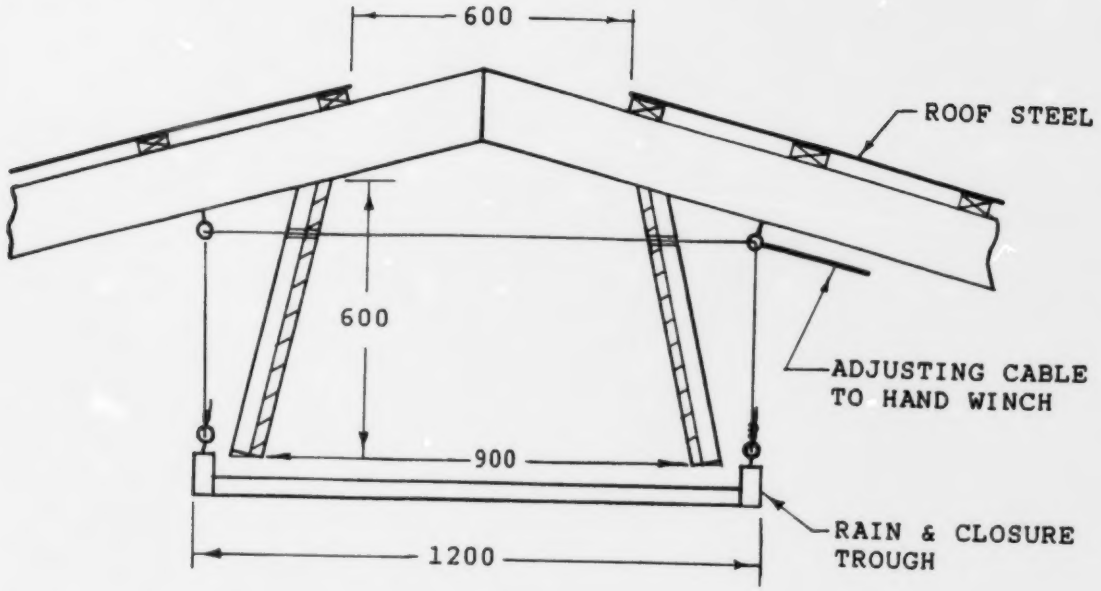

Figure 2: Sketch of the Exhaust Ridge Opening and Rain Trough Location. (All Dimensions mm).

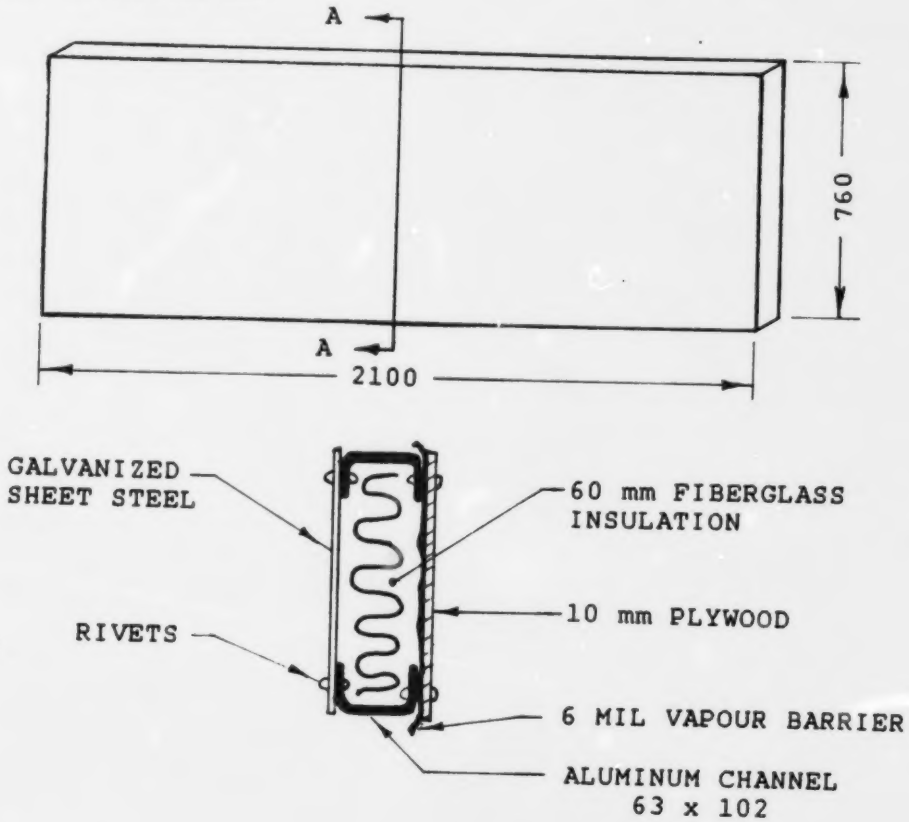

Figure 3: Sketch of Bottom Pivoting Wall Vent. (all Dimensions mm).

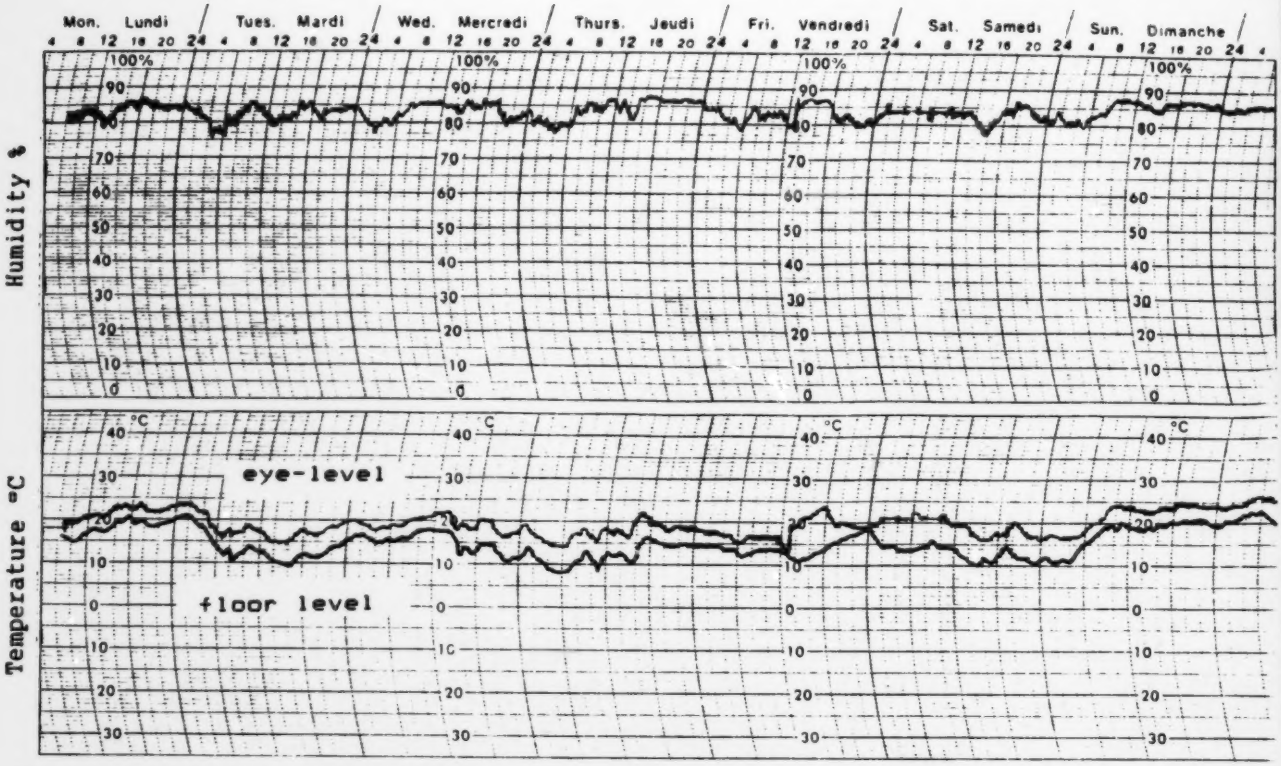

Figure 4: Temperature and Humidity for the Week Starting December 17, 1984, Typical Winter Performance.

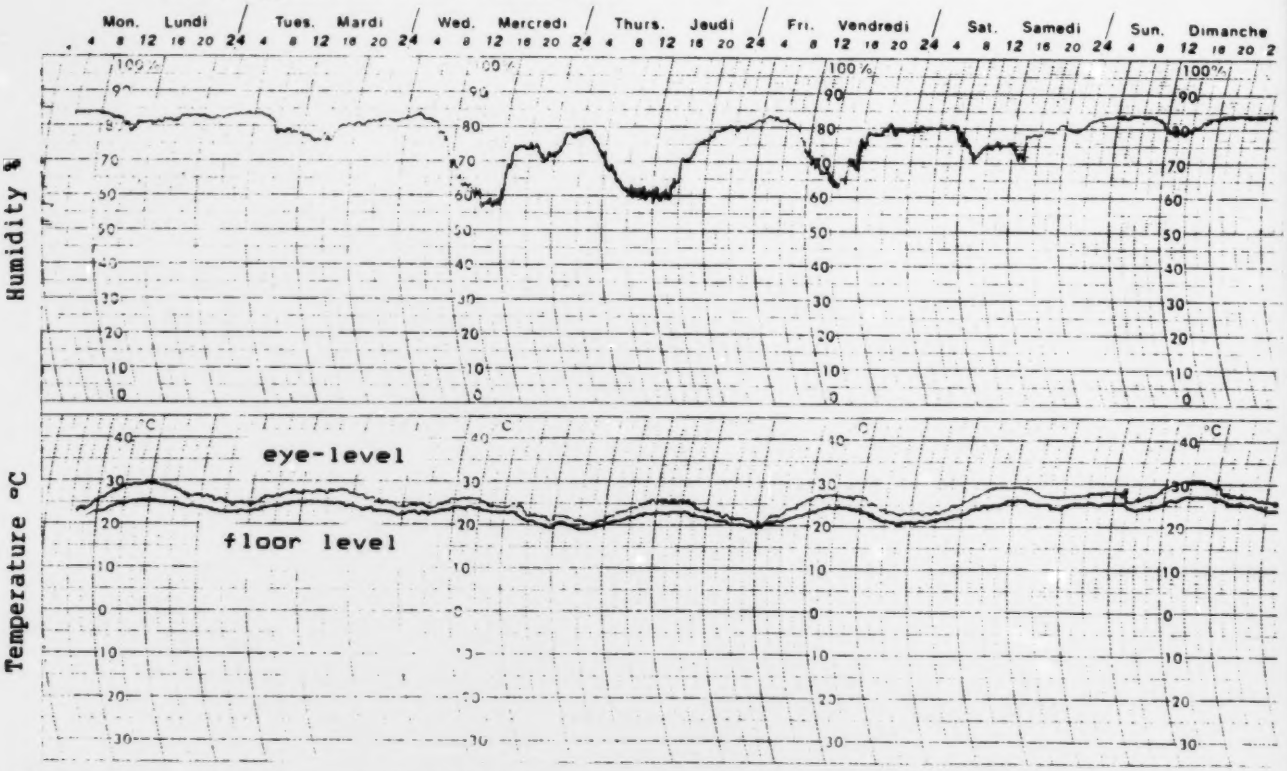

Figure 5: Temperature and Humidity for the Week Starting July 7, 1985, Typical Summer Performance.

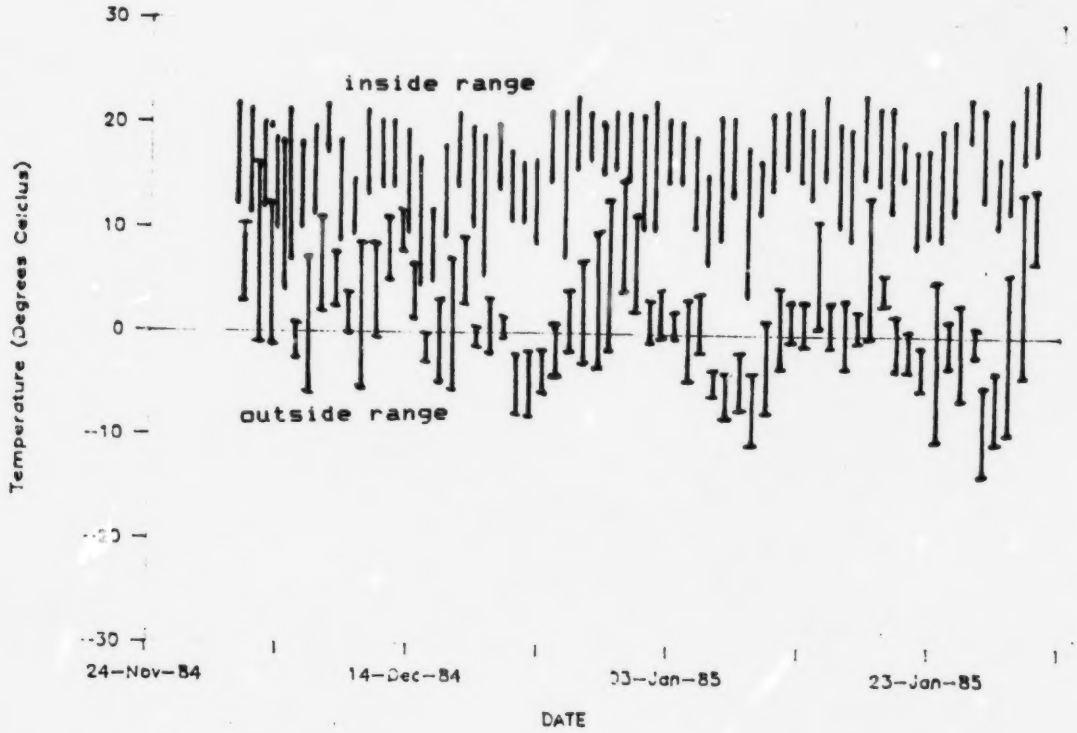

Figure 6: Daily Maximum to Minimum Temperature Range Recorded in the Barn and at Stratford for December 1984 and January 1985.

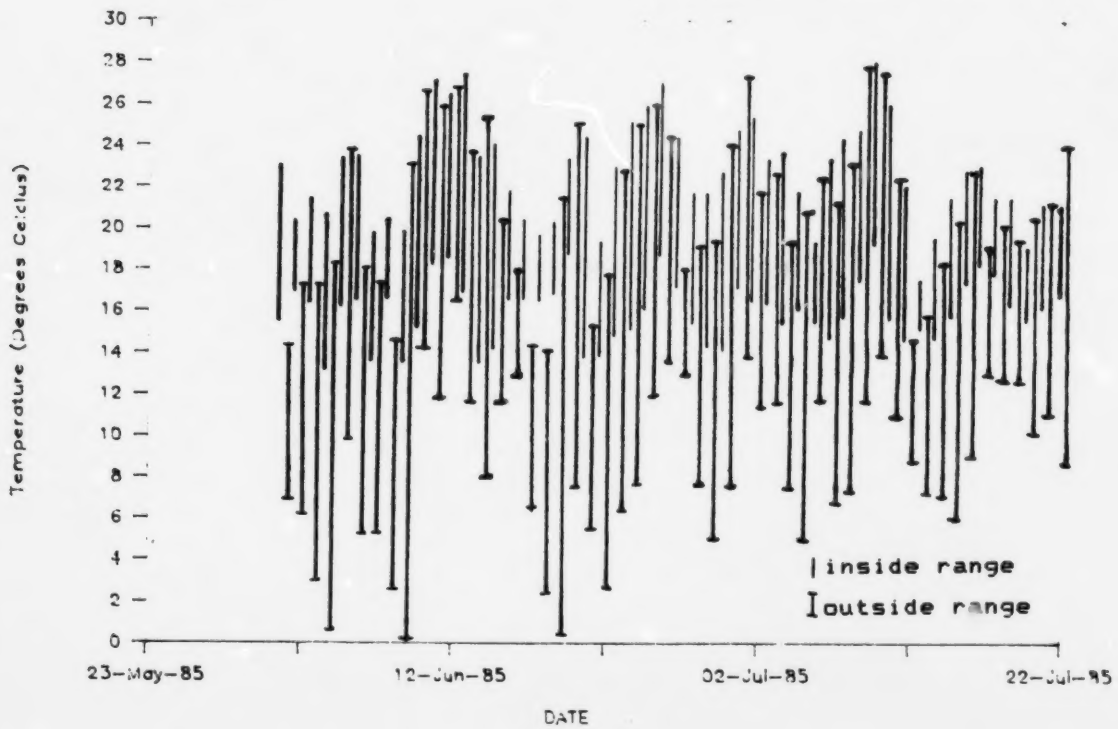

Figure 7: Daily Maximum to Minimum Temperature Ranges Recorded in the Barn and at Stratford for June and July 1985.

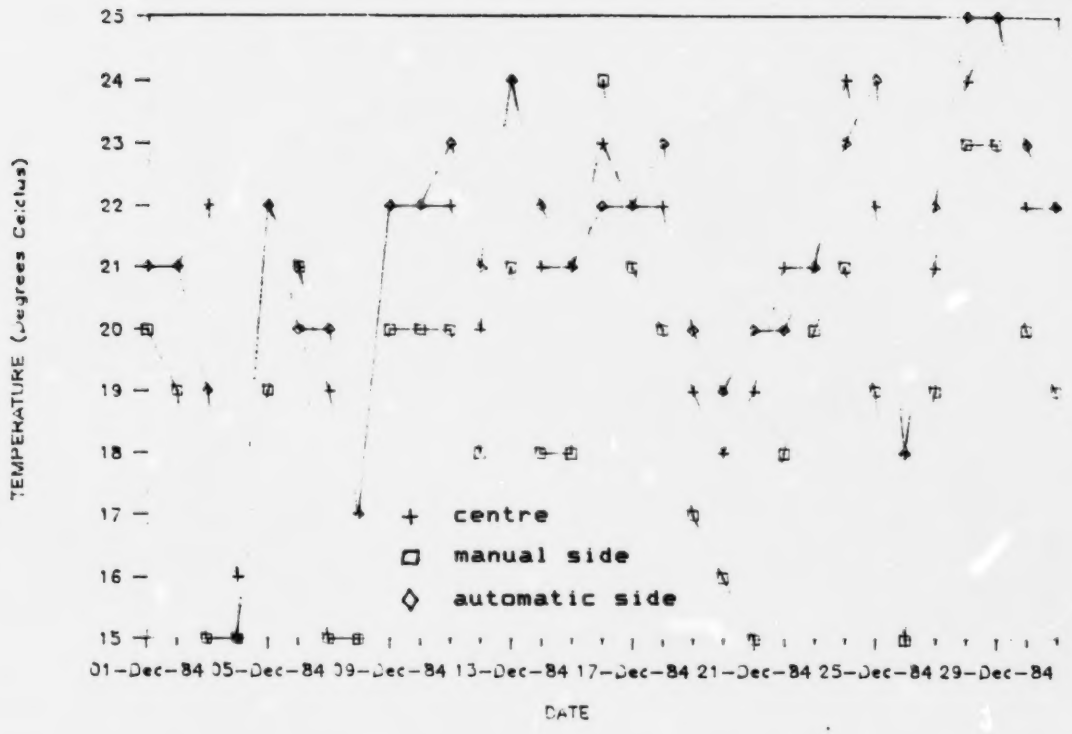

Figure 8: Daily Maximum Temperature at Three Eye-Level Locations in the Feeder Barn for December 1985.

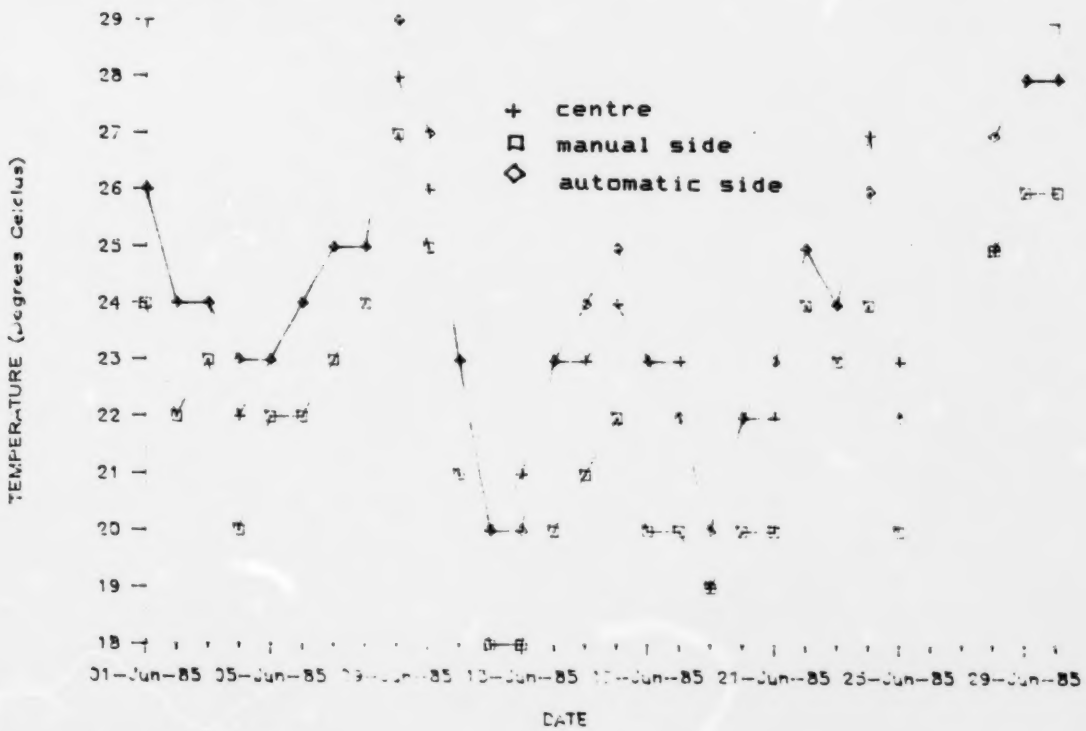

Figure 9: Daily Maximum Temperature at Three Eye-Level Locations in the Feeder Barn for June 1985.

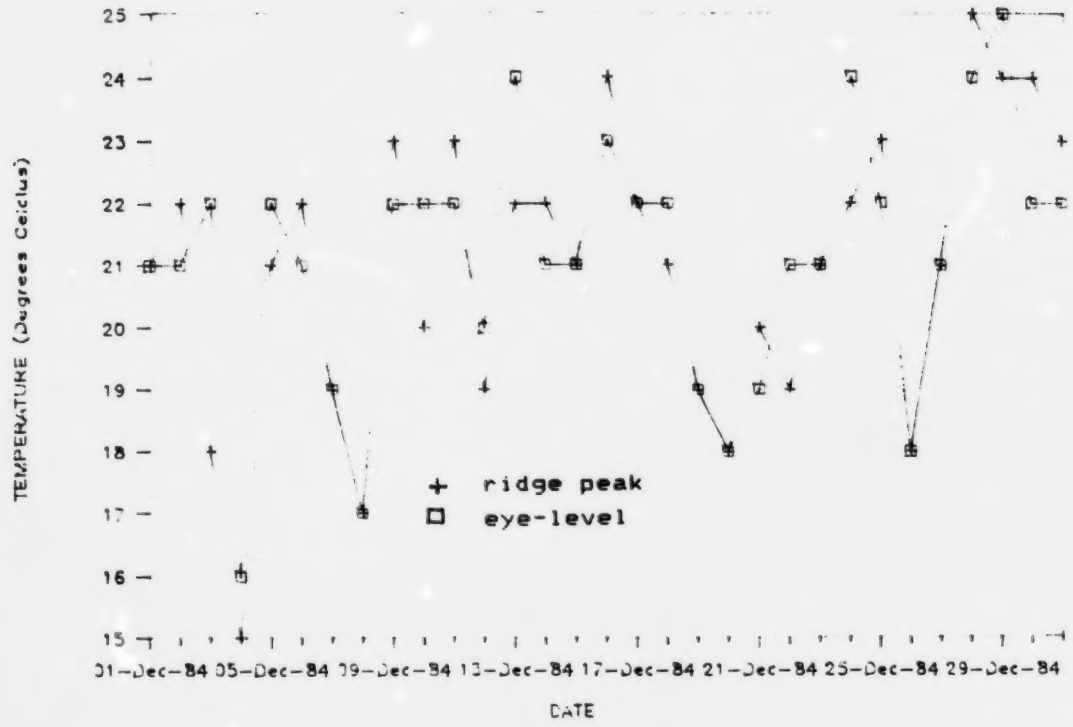

Figure 10: Daily Maximum Temperature at the Centre, Eye-Level Location and at the Ridge Peak of the Feeder Barn for December 1985.

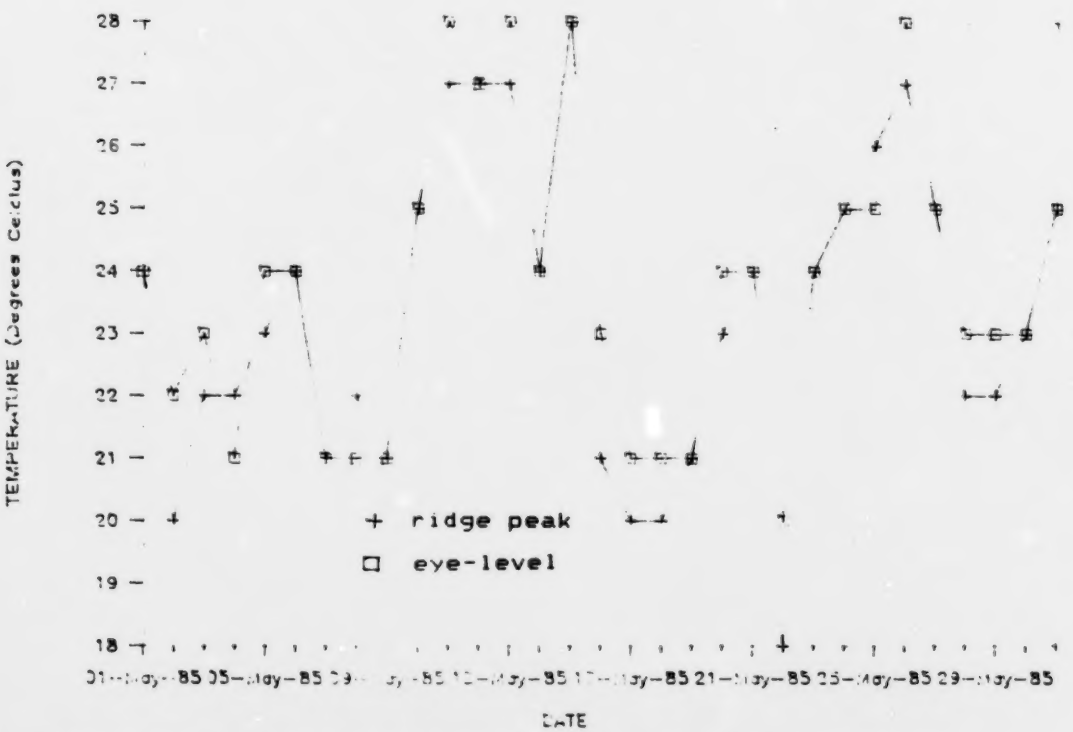

Figure 11: Maximum Daily Temperature at the Centre, Eye-Level Location and at the Ridge Peak of the Feeder Barn for May 1986.

APPENDIX 1. Calculations for Ventilation Cost Reduction.

In order to estimate the cost savings realized by converting to a natural ventilation system, the ventilation cost was estimated using the following procedure:

1. The O.M.A.F. ventilation program NVENT was run on the computer for the barn parameters to determine the ventilation requirements for different outside temperatures. A minimum ventilation rate of 1450 L/s was used to ensure 4 air changes per hour. These reccommended ventilation rates are shown in Table A-1.

2. Average monthly outside temperatures were determined from Environment Canada weather records for Stratford MOE, Ontario, from 15 years of records. These values are shown in Table A-1 as Design Temperature.

3. Average monthly ventilation rates were estimated for the barn by interpolating for a ventilation rate from the NVENT output for each of the design temperatures listed.

4. The daily fan running time for each month was estimated by determining the running time of each fan required to provide the recommended ventilation rate. The fans installed in the barn are described as follows:

Stage	Description	Rated Output
1	12" single speed	600 L/s
2	12" single speed	600 L/s
3	18" single speed	1750 L/s
4	18" single speed	1750 L/s
5	36" single speed	5000 L/s
6	36" single speed	5000 L/s

5. The electrical energy consumption , and the operating costs of the fans were calculated using the following assumptions.

   a. An average fan efficiency of 85% .
   b. The cost of electricity is $0.05/kWh

$$\text{monthly power consumption, kWh} = \frac{\text{power rating, W}}{\text{motor efficiency}} \times \frac{\text{hours running}}{\text{day}} \times \frac{\text{days}}{\text{month}} \times \frac{1\text{kW}}{1000\text{W}}$$

where:
- power rating is the rated fan motor power = 373W (1/2 h.p.)
- hours running is the average daily hours of fans running from Table A-1.
- motor efficiency of the fan motor is equal to the rated power output divided by the input power consumed. This expression accounts for the energy loses in converting electrical energy to mechanical energy.

$$\text{monthly cost, \$} = \frac{\text{kWh}}{\text{month}} \times \frac{\$0.05}{\text{kWh}}$$

6. Sample Calculations

$$\text{January power consumption} = \frac{373\ \text{W}}{.85} \times \frac{52\ \text{h}}{\text{d}} \times \frac{31\ \text{d}}{\text{month}} \times \frac{1\ \text{kW}}{1000\ \text{W}}$$

$$= 710\ \text{kWh}$$

$$\text{January electricity cost} = 710\ \text{kWh} \times \$0.05/\text{kWh}$$

$$= \$36$$

Table A-1: Estimation of Fan Operating Cost

Month	Design Temp.	Ventilation Rate (L/s)	Daily Operating Hours at Each Fan Stage 1	2	3	4	5	6	Total Hours Per Day	No.Days in Month	Electrical Consumption (kWh)	($)
Jan	-7.9	1450	24	24	4	0	0	0	52	31	710	$36
Feb	-7.2	1450	24	24	4	0	0	0	52	28	640	$32
Mar	-2.2	1850	24	24	9	0	0	0	57	31	780	$39
Apr	5.6	3000	24	24	24	1	0	0	73	30	960	$48
May	11.6	5000	24	24	24	24	2	0	98	31	1330	$67
Jun	16.8	14000	24	24	24	24	24	21	141	30	1860	$94
Jul	19.2	20400*	24	24	24	24	24	24	144	31	1960	$99
Aug	18.6	18000*	24	24	24	24	24	24	144	31	1960	$99
Sep	14.5	12000	24	24	24	24	24	11	131	30	1720	$87
Oct	8.7	4500	24	24	24	22	0	0	94	31	1280	$65
Nov	2.3	2500	24	24	18	0	0	0	66	30	870	$44
Dec	-4.6	1650	24	24	7	0	0	0	55	31	750	$38
											=======	=======
									Estimated Annual Electricity to Operate Fans		14800 kWh	
									Estimated Annual Cost of Ventilation			$748

* Note: The capacity of the six fans is 14 700 L/s. The ventilation requirement from NVENT for July and August for a full barn exceeds this. However, Since the barn was filled to 75% capacity, these fans should have provided adequate ventilation.